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Study of reconfigurable printed antennas for GPS applications

Roberto G. Rojas, Nuttawit Surittikul, K.W. Lee and Siddharth Iyer

The Ohio State University
ElectroScience Laboratory
Department of Electrical & Computer Engineering
1320 Kinnear Road
Columbus, Ohio 43212-1191

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Roberto G. Rojas
Nuttawit Surittikul
K. W. Lee
Siddharth Iyer

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14. ABSTRACT

This report addresses issues concerning the design, analysis and implementation of circularly polarized pattern reconfigurable printed antennas. Single and multi-layer dual band staked microstrip patches mounted on substrates/superstrates of square and octagonal shape are proposed for GPS applications. Another objective of the research described here was also to develop an accurate model for the analysis and design of switching circuits for pattern reconfigurable antennas. Modeling of all switch circuit components and accounting for the effects of the other elements like the bias lines is seen to be crucial in the design of the switch circuit, and in turn to the performance of the antenna. The design of the switching circuits is done for a single band antenna, operating at the GPS frequency of 1.575 GHz (L1) and for a dual band antenna, which operates at the 2 GPS frequencies of 1.227 GHz (L2) and L1. The single band antenna is implemented and measured. Simulated and measured results of the radiated field for this antenna are compared and found to agree fairly well.

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1. Objectives

The purpose of this study is to develop and implement novel concepts for reconfigurable printed antennas for application in the global positioning system (GPS). Although there are a variety of reconfigurable concepts (frequency, polarization), this study deals with pattern reconfigurability in real time. In particular, low cost, single and dual band circularly polarized stacked printed antenna that can adjust their beamwidth in real time are investigated. This is being accomplished by means of design and analysis, computer simulation as well as implementation of prototypes and measurements. Numerical techniques such as finite difference time domain (FDTD), Method of Moments (MoM) and finite element method (FEM) are employed to obtain numerical results of radiation patterns, input impedance, polarization properties, etc. Once the designs are finalized, the antennas are implemented and measured to access the feasibility of the proposed concepts.

2. Status of Effort

The antenna that possesses the ability to modify its radiation properties in real time is referred to as a reconfigurable antenna. Low cost antennas that can adjust their radiation patterns in real time are needed in the presence of intentional or unintentional interfering signals, which are assumed to be incident along the horizon. Hence in the presence of jamming signals, the reconfigurable antenna is required to adjust its antenna beamwidth to suppress these undesired signals as much as possible. The work described here deals with the design and analysis of radiation pattern reconfigurable concepts where passive microstrip antenna elements are integrated with RF switches. Analysis and design schemes have been developed to model the antenna as well as the switches (diodes), biasing lines, etc. Although the switches can be electronic, RF MEMS or photonic devices, diode switches are currently being used in our designs.

The principle of operation for the proposed antenna is based on the modification of the characteristic of the induced surface waves. In most printed antenna design, the antenna is generally designed to avoid the use of electrically thick substrate due to the excitation of the surface waves. These surface waves are considered as a loss mechanism because they radiate to free space at the truncation/edge of the substrate distorting the main beam radiation pattern and raising the level of the sidelobes as well as the backlobes. On the other hand, electrically thick microstrip antennas have the advantage of providing a larger operational bandwidth over microstrip antennas mounted on thin substrates. Our proposed reconfigurable scheme is, however, based on the modification of the EM propagation characteristics of the surface waves, and thus the radiation pattern, by using a metallic parasitic structure loaded with switches, such that the diffracted surface waves contribute constructively (in phase) or destructively (out of phase) to the main beam pattern. The radiation pattern is, therefore, controlled by the two operating states of the switch (on/off).

Two key schemes for controlling the radiation pattern, especially around the horizon, have been developed, namely, control of the vertical field component (scheme I) and control of the horizontal field component (scheme II). The first scheme, "control of vertical field component", consists of a patch antenna surrounded by a switch loaded ring. The effective width of the parasitic ring can be adjusted by activating the switches.

The switches, diodes in this case, are assumed to have two states of operation, namely, *on* and *off*. Ideally, the *on* state allows the current to flow through the switches, while the off state does not. By changing the effective width of the ring, the vertical field component along the horizon can be modified.

The second scheme, "control of horizontal field component", consists of the same patch antenna, however, it is surrounded by a narrow (in width) parasitic ring. The switches are placed along the circumference of the ring and thus control the length of the various segments making up the ring along its circumference. Also note that in order for this scheme to work, the ground plane of the antenna must be smaller than the substrate. Similarly, by activating the switches loaded on the ring, there is nearly an 8-10 dB drop in the horizontal field component along the horizon, while the vertical component remains almost the same.

The antennas described above are designed to operate at a single frequency, L1 (1.575 GHz). Nevertheless, there is also a need for a dual frequency antenna in GPS application, as GPS operates at two frequency bands, namely, L1 (1.575 GHz) and L2 (1.227 GHz). A new design for a three layer reconfigurable circularly polarized dual band stacked patch antenna is currently being completed. The antenna consists of two stacked patches in the bottom two layers and two parasitic strips/rings on the top two layers. The upper radiating patch is designed to resonate at the L1 band, while the lower patch is designed to operate at the L2 band. Note that only the top parasitic structure is loaded with the diode switches.

Both parasitic structures, the upper switch loaded ring and the lower passive (no switches) parasitic ring, are octagonal in shape for symmetry purposes. In addition, the antenna substrate is also of octagonal shape.

3. Accomplishments

This section addresses the progress in the design and implementation of the reconfigurable antennas, both single and dual band.

- To verify that our proposed schemes work in practice, a single band antenna for controlling horizontal field component was design, optimized, implemented and tested as shown in Figure 1. The substrate has a dielectric constant of 9.2 with a thickness of 0.8 mm. The dimensions of the square substrate are 7 square inches in each side. To excite a circularly polarized radiation pattern, the antenna is fed by 4 probes with equal magnitude and 90 degree phase increment between adjacent input signals. Figure 2 shows the measured horizontal field component versus angle of the proposed antenna. By turning the diode switches on and off, the horizontal field component, i.e., phi component is modified by nearly 4-6 dB along the horizon. On the other hand, although not shown here, the vertical field component, i.e., theta component, remains almost unchanged between the two states of the switch operation, as expected.

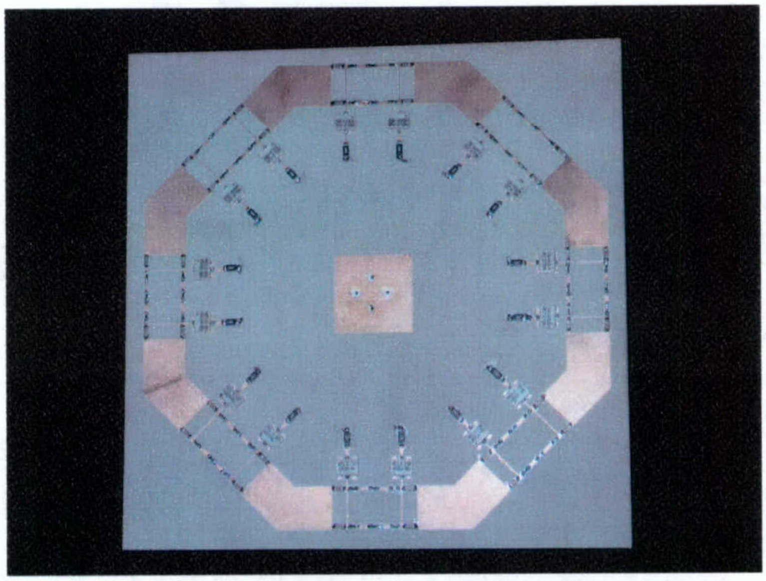

Figure 1: Geometry of the implemented reconfigurable single band GPS antenna.

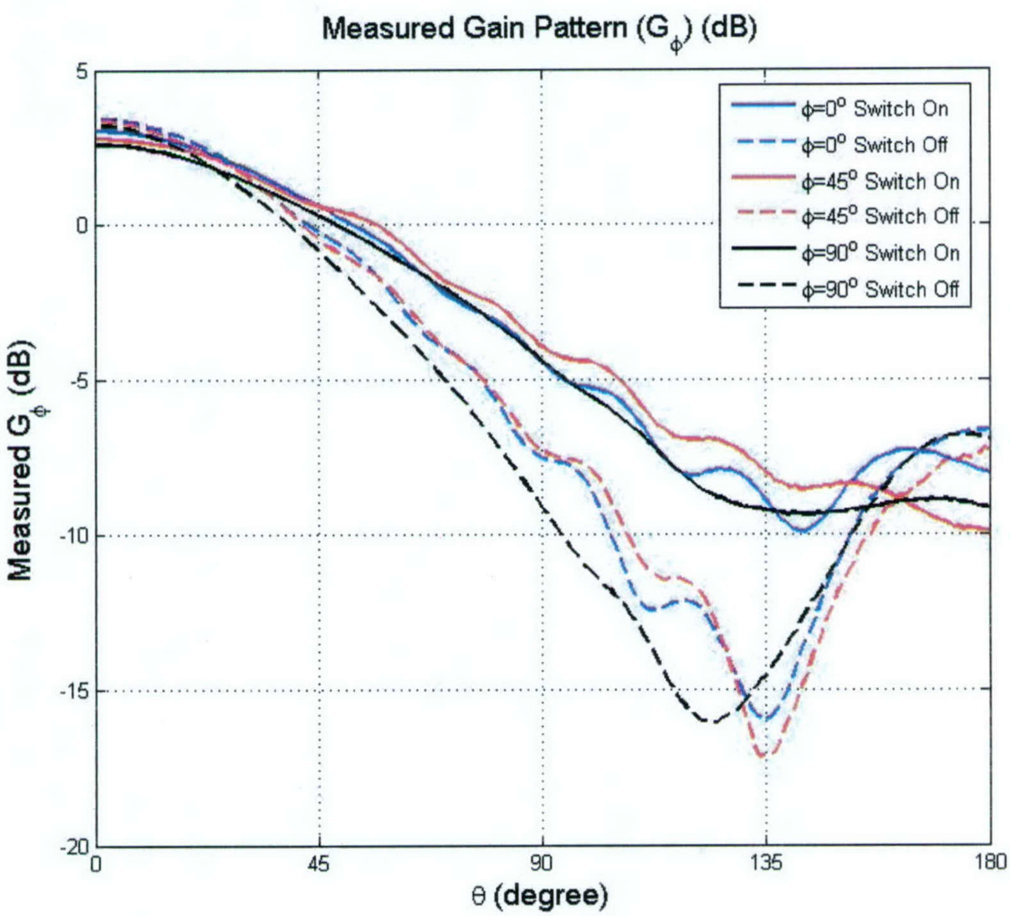

Figure 2: Measured gain patterns of the horizontal field component for the *on* and *off* states of the switches for various azimuth planes.

- The progress made on the design of the reconfigurable dual band antenna is summarized below. The keys issues to be addressed are the feeding configuration and input impedance, feeding circuitry, design of the parasitic structures including the switching circuits.

  i. As it is well known, GPS antennas must be circularly polarized (CP) to alleviate multi-path issues. The CP pattern can be obtained by exciting two orthogonal current modes with 90° phase difference. In our proposed geometry, each radiating patch is excited with four feeding probes of equal magnitude with 90° phase increment, making a total of eight probes. The locations of the eight probes as well as the calculated input impedance were obtained using computer simulations, and then compared to the measured results. We found some small discrepancies between the measured and simulated results in terms of the resonant frequencies and input impedance. The measured resonant frequencies seem to be slightly higher than the resonances obtained from the simulation. The discrepancy may be introduced during the fabrication process, since we also observe an electrically small air gap at the interface of each substrate, which could modify the effective dielectric constant of the three layer substrates.

  ii. The second topic deals with the design of the feeding circuit for the dual band antenna. The power divider circuit for feeding the dual band antenna has been designed. The required power divider is a two stage power divider. This is because there are four feed points per band, and each power divider provides two outputs. The outputs of the first power divider are fed to two other power dividers, which provide the four equal magnitude (theoretical -6 dB) outputs. The four feed points need to be 90° out of phase with respect to each other; hence some of the feed lines need to be lengthened in order to provide the necessary phase shift. This makes the design of the feed circuit somewhat involved, since there are three power dividers per band, making a total of six power dividers to be fit on the same substrate. Furthermore, the feed points for the L1 patch are in very close proximity to each other, and there is also not much clearance between a feed point for the L1 patch and a corresponding feed point for the L2 patch, making the routing of the power divider lines to the respective feed points more challenging.

  iii. The feed circuitry is designed using Agilent ADS and simulated using Momentum (based on the Method of Moments) in order to check the performance of the power dividers over their respective bands of interest. The bandwidth at each band should be at least 24 MHz centered at the respective center frequency (1.227 GHz for L2 and 1.575 GHz for L1). Measured results show that over the bandwidth of interest, there is a 0.2 dB deviation in the magnitudes of the four output signals, while there is approximately a 90° progressive phase rotation between them. Further optimization was performed to bring the phase rotation to 90°.

  iv. The last task is the design of the parasitic structures as well as the switching circuits. As mentioned in the previous section, the radiation pattern obtained from the new proposed geometry with no parasitic structure is azimuthally symmetric at both the L1 and L2 bands owing to the symmetry of the structure itself. The parasitic structure is also chosen to be an octagonal shape to maintain the symmetric radiation pattern. The goal of the proposed design is to control the

vertical field component (theta component) in the vicinity of the horizon. The design principle is to obtain a parasitic structure whose radiated field in one of the two operating states of the switches (*on* or *off*) cancels out the field radiated by the patch, especially along the horizon. As a result, the total field is very weak along the desired region.

The parameters considered in the design so far have been the width of the upper parasitic ring, the location of this ring, and the location of the lower parasitic structure. A thin ring is being used for the lower parasitic structure. By varying these parameters, 2 widths of the upper structure are sought, which differ by at least 15-20 mm. The configuration with the larger width will provide a drop in the pattern of the vertical component of the electric field around the horizon, while the configuration with the smaller width will not produce such a large drop, thereby producing the reconfigurability. The difference in width of these 2 configurations is needed to insert the switch circuit components.

Thus far, following the procedure mentioned above, reconfigurability in the order of 8-9 dB has been obtained. It is the goal of this research to obtain a larger change in the pattern of the antenna between the two states of switch operation (on/off), and hence further optimizations need to be performed. The parameters that have been considered so far have only been the width and location of the upper parasitic structure, and the location of the lower parasitic structure. Other parameters like the thickness of the substrate layers and the dielectric constants of each layer in the antenna are also available for consideration in the design process. These parameters are currently being investigated, and optimum values are being sought in order to obtain greater reconfigurability than is currently achievable. Once these parameters have been fixed, the switch circuits will need to be inserted into the switching ring. Further optimizations will be carried out with the additional parameters that the switch circuits introduce, namely, the number of switching diodes used, the positioning of various bias components, bias lines, etc., in order to obtain the maximum pattern reconfigurability at the L1 and L2 frequencies of operation.

4. Personnel Supported

- Prof. Roberto Rojas, PI.
- Nuttawit Surittikul, Graduate Student (25% support).
- Siddharth Iyer, Graduate Student (25% support), graduated with MS degree, Summer 2004.

5. Technical Publications

- Peer Reviewed Journal Publications

1. R.G. Rojas and K.W. Lee*, "Surface wave control in printed antennas using non-periodic parasitic strips," *IEE Proceedings Microwaves, Antennas and Propagat.*, vol. 148, pp.25-28, Feb. 2001

- Peer Reviewed Conference Proceedings

  1. S. Iyer and R.G. Rojas, "Design and Analysis of Switching Circuits for Reconfigurable Antennas," *IEEE International Antennas and Propagation Symposium and USNC/CNC/URSI North American Radio Science Meeting*, Monterey, CA, June 2004.
  2. N. Surittikul and R.G. Rojas, "Analysis of Reconfigurable Printed Antenna using Characteristic Modes: FDTD Approach," *IEEE International Antennas and Propagation Symposium and USNC/CNC/URSI North American Radio Science Meeting,* Monterey, CA, June 2004.
  3. N. Surittikul and R.G. Rojas and K.W. Lee, "Reconfigurable Circularly Polarized Dual Band Stacked Microstrip Antenna", *IEEE AP-S International Symposium and USNC/URSI National Radio Science Meeting*, Columbus, OH, June 22-27, 2003.
  4. K.W. Lee and N. Surittikul and R.G. Rojas, "Surface Wave Control for Reconfigurable Printed Antenna Applications", *IEEE AP-S International Symposium and USNC/URSI National Radio Science Meeting*, San Antonio, TX, June 16-21, 2002, **(invited)**.
  5. R. G. Rojas and K.W. Lee and N. Surittikul, "Reconfigurable GPS Antenna", *National Radio Science Meeting (URSI)*, Boulder, CO, January 9-12, 2002 (**invited**).

- Journal Paper in Review

  N. Surittikul, S. Iyer, R.G. Rojas and K. W. Lee, "Pattern Reconfigurable Printed Antenna for GPS Applications," submitted to *IEEE Transactions on Antennas and Propagation*, special issue on Multifunction Antennas and Antenna Systems.

- Journal Papers in Preparation:

  1. N. Surittikul and R.G. Rojas, "Analysis of Reconfigurable Printed Antenna using Theory of Characteristic Modes: FDTD Approach," to be submitted to *IEEE Transactions on Antennas and Propagation.*
  2. N. Surittikul, S. Iyer and R.G. Rojas, "Dual Band Reconfigurable Stacked Microstrip Antenna for GPS Applications," to be submitted to *IEEE Transactions on Antennas and Propagation.*
  3. K. W. Lee, N. Surittikul, R. G. Rojas and S. Iyer, "A Pattern Reconfigurable Microstrip Antenna Element," to be submitted to *IEEE Electronic Letters*.

6. Interactions/Transitions

- Scholarly Presentations

1. N. Surittikul and R.G. Rojas, "Reconfigurable Circularly Polarized Dual Band Stacked Microstrip Antenna", *EM range consortium meeting*, Columbus, OH, August, 2003.

2. R.G. Rojas and K.W. Lee and N. Surittikul, "Reconfigurable GPS Antenna", *EM range consortium meeting*, Columbus, OH, July 31, August 1, 2001.

- Transitions

Mr. Kevin Sickles at the AFRL/SNRR, Wright Patterson Air Force Base, has supported for approximately one year (August 2003-October 2004) a graduate student to build and test a reconfigurable antenna. The antenna has been designed and a prototype built. It is currently being tested before it is delivered to Mr. Sickles. One possible application for this reconfigurable antenna is for use by the Predator UAV. We are also currently discussing with other AFRL/SNRR personnel the design of an array of GPS antennas.

Point of Contact:

Kevin Sickles
WPAFB/AFRL/SNRR
2241 Avionics Circle
WPAFB, Bldg 620
Dayton, OH 45433-7318

Phone: (937) 255-6427 ext. 4224
Fax 937-255-8086

7. Patent Disclosures

None

8. Honors

ElectroScience Laboratory Outstanding Technical Report of 2003: R.G. Rojas and N. Surittikul, "Reconfigurable Dual Band Stacked Microstrip Antenna for GPS Applications."